CHAPTER 4

HYDRAULICS

4-1. Headloss and System Curves

a. General, The location and required capacity of a potable water pumping installation will be determined from a hydraulic network analysis of the distribution system. Pumping requirements for various design conditions at one or several locations can be simulated for varying flow rates over extended periods of time by use of computer programs. Refer to appendix B for available computer programs. Based on this information, the pump station including suction and discharge piping systems will be designed. To make an accurate determination of the head requirements, a system head curve must be derived depicting calculated losses through the system for various pumping rates. A schematic should be drawn showing configuration and size of all piping including valves and fittings. Information on system headloss calculations can be found in TM 5-813-5. Pumps at the pump stations will be sized to handle individually and in combination the maximum projected daily consumption, the peak hourly rate plus fire load demand, and the estimated minimum hourly rate at some future date. Refer to appendix C for a case study for adding pumps to an existing distribution system. The pump discharge head will be the required pressure needed at the point of connection to the distribution system plus the pumping station and pump discharge and suction piping head loss. Example problems and information on friction loss in suction and discharge piping will be found in the Hydraulic Institute Engineering Data Book. A design analysis will be prepared to show head loss and friction calculations for present and future demands.

b. System head curves. In every case where liquid is transported from a point A to a point B, there is a friction loss through the piping system between the two points, and there may be an elevation or pressure differential. A simplified system head curve is shown in figure 4-1.
After analyzing the actual system to determine its requirements, it is good practice to plot the system head curve for any flow rate from 0 to beyond the pump station required peak capacity knowing that the friction loss will be 0 at 0 gum flow.

c. Pump selections. With the system defined, pumps will be selected. The point of intersection between the pump performance curve and the system head curve represents the capacity at which

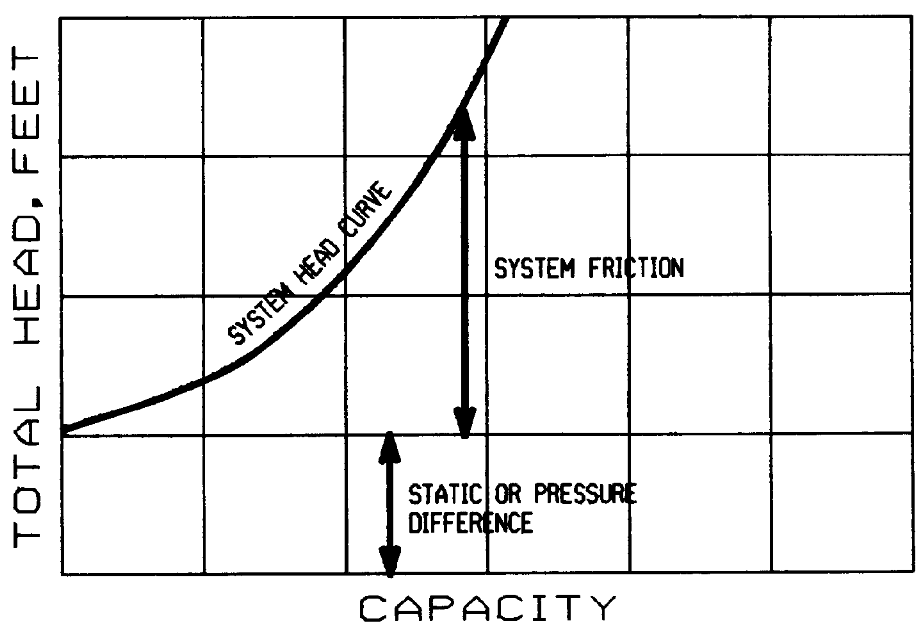

Figure 4-1. System Head Curve.

the pump will operate. Whenever possible, it is always advisable to select and operate pumps so that they will normally operate in a region of reasonable capacities; that is, not too far to the left or to the right of their best efficiency point. These operating limits should be well within the recommended operating limits set by the manufacturer. A pumping installation will often have fluctuating pressure differential depending on distribution system demand and pressure conditions or on water level in a storage tank. In this case, the system curve moves up or down as the pumping cycle progresses and the pump selection becomes more critical. It is important to select the pumps so that they will operate within safe operating limits near the best efficiency point for both the high and the low system head conditions. For small pumps, when net positive suction head (NPSH) is critical, minimum flow limitations of about 25% of capacity at the best efficiency point should be imposed. Large high horsepower pumps have minimum flow limitations as high as 70% of the capacity at the best efficiency point.

d. Parallel operation. In parallel operation two or more pumps discharge into a common header. Usually, pumps operating in parallel will have the same cut-off head. In a station with three constant speed pumps, with the larger pump out of service, the two smaller pumps will operate with pump curves illustrated in figure 4-2. According to the reliability factor these two pumps running together in a three pump station must handle 100 percent of peak flow. Each pump alone will pump 60% of this flow. Figure 4-3 shows a possible arrangement for a large station. Peak flow is handled by four constant speed pumps in parallel. As the pressure increases pumps can be deenergized one at a time so that the entire range of expected demands can be covered in such a manner that each pump is always operating at a capacity near its best efficiency point. The illustration shown is not the best pump selection for this system since the increase in capacity gained when going from a three to a four pump operation is negligible. The fourth pump adds little to the total discharge capacity. For this system a better arrangement would be to increase the pump capacities slightly and use a three pump system. In any case, the reliability factor will dictate that peak demand will be met with the largest pump out of service. This illustrates the need to compare carefully the characteristics of the pump and the system head curve.

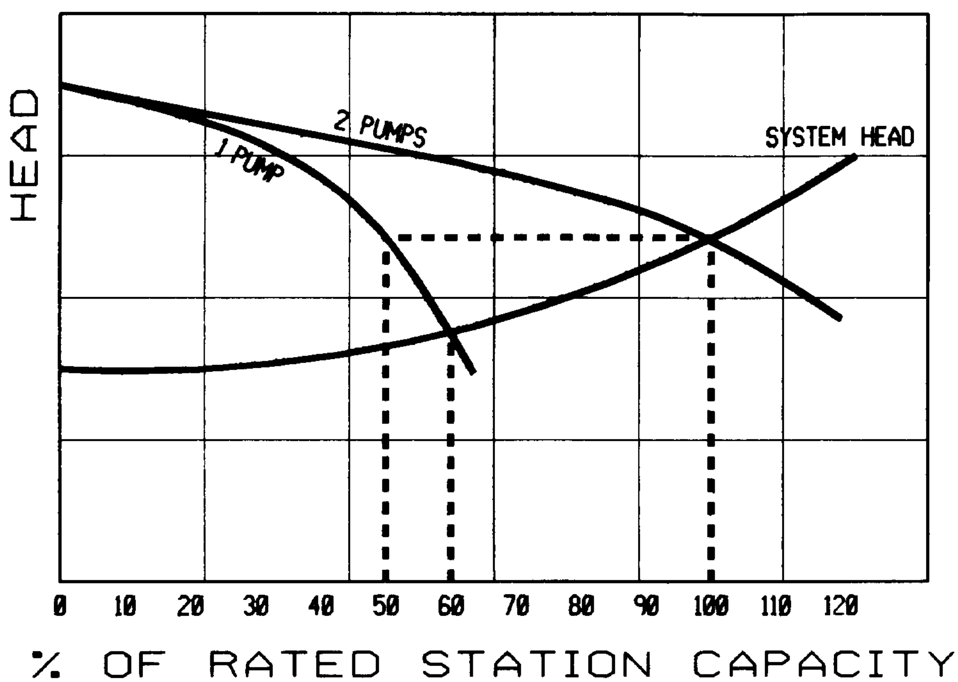

Figure 4–2. Two Constant Speed Pumps Operated in Parallel.

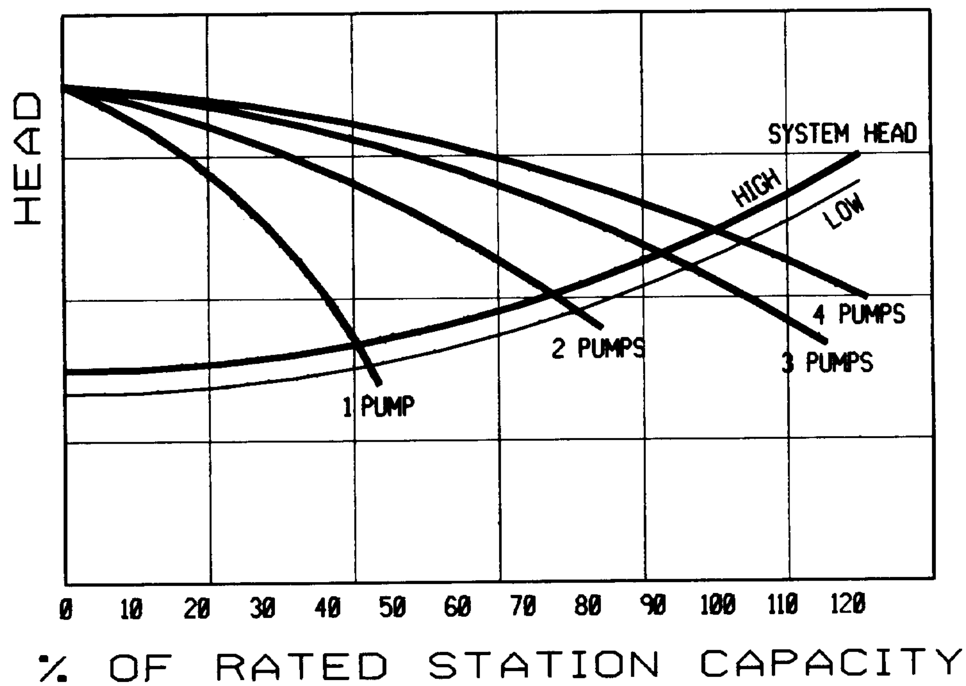

Figure 4–3. Four Constant Speed Pumps of Equal Capacity.

4-2. Pump Cavitation.

a. Cavitation is a term used to describe a phenomenon that may occur in a pumping installation and may occur in piping systems because of liquid velocity changes. Cavitation in centrifugal pumps is explained in TM 5-813-5. Cavitation in pipe lines may take place at sudden enlargements of the pipe cross section, at sharp bends, throttled valves or similar situations. The designer should avoid the following conditions for centrifugal pumps:

(1) Operating heads much lower than rated head at peak efficiency of the pump.

(2) Operating capacities much higher than rated capacity at peak efficiency of the pump.

(3) Suction lift higher or positive suction head lower than recommended by the manufacturer.

(4) Liquid temperatures higher than that for which the system was originally designed.

(5) Pump speeds higher than manufacturer's recommendations.

b. For propeller pumps, the designer should avoid these conditions except conditions (1) and (2) will be stated as follows:

(1) Operating heads much higher than peak efficiency of the pump.

(2) Operating capacities much lower than capacity at peak efficiency of the pump. Cavitation will not be a problem in a pump installation if the system is designed, selected, installed, and operated in accordance with the recommendations of the designer and the manufacturer.

4-3. Surge Analysis

a. General. Surges in pipelines carrying liquids are usually caused by opening, closing or regulating valves or pumps starting and stopping. These surges, also called hydraulic transients may range in importance from a slight pressure or velocity change to sufficiently high pressure or vacuum to rupture the piping system, to damage pumping equipment and cause extensive shutdown time. Water hammer, a result of hydraulic transients, will occur when the total surge pressure exceeds approximately twice the value of the static pressure in the system when the fluid is at rest. "Water hammer" is discussed in TM 5-813-5. Surge protection analysis will be performed on critical sections of the piping system to verify design and surge control equipment selection. If excess transient pressures are predicted by the analysis, design and mechanical equipment application will be modified. Hydraulic surge control is a specialized field. If a detailed surge protection study is required, it should be provided by engineers or consulting engineering firms specialized in this field. Detailed pipeline surge analysis by an expert should be considered under the following design conditions:

(1) Generally, if the interaction of pump station, piping system, valves and control system is complex following a power failure or during startup conditions.

(2) If power failure at the pump station would result in significant reverse flow, which can slam check valves or cause a fluid rejoinder surge. In a system with a flat pipeline profile, reverse flow surges are usually not significant. In a system where the pumps work against a significant static lift, surge pressures can be many times the maximum steady state operating pressure.

(3) If the pipeline profile has significant intermediate high points where the fluid may separate, following power failure, and result in high surge pressures upon rejoining.

(4) If the pump station or individual pump take suction through a pipeline of significant length (several hundred feet) a power failure may result in high pressure heads. For pumps located immediately adjacent to storage tanks, suction line pressure transients are usually insignificant.

(5) If the pump station is equipped with discharge check valves and air vessels, the check valves may be slammed shut by the air vessel or parallel connected pumps following power failure.

(6) If the preliminary hand calculations indicate that surge control equipment is required in the system, optimum performance and surge control equipment selection could be established through detailed surge analysis. As a general rule; surge analysis should be performed for vertical turbine pump installations and any pump installation where individual pump capacity exceeds 500 gum. A typical checklist of information required for a detailed surge and water hammer analysis is shown in figure 4-4. The example in figure 4-5 shows the total surge head exceeding the allowable surge head for a pipeline.

(7) Specialized computer programs for hydraulic transient analysis are listed in Appendix B. A case study for control for hydraulic transients created due to power failure and when using air-vacuum valves is included in Appendix D.

b. Surge control methods. The most common devices to overcome the effects of excessive hydraulic surge pressures in water pumping systems include —

(1) Spring or weight-loaded check valves, which are designed to close before the hydraulic pressure wave reverses. This device may protect the pump but will not eliminate the water hammer in the rest of the system.

(2) Surge relief valves, which will open at a preset surge pressure but do not prevent the occurrence of the water hammer. They are frequently used as a back-up for other control methods. Several manifold mounted relief valves will be considered in lieu of one large relief valve to minimize water wastage.

(3) Air cushioned surge tanks, which will absorb pressure increases in stopping and starting pumps. If properly designed they will reduce pressures to protect the system. Space requirements and costs have limited their usage in water pumping systems. Hydropneumatic tanks used in connection with smaller water pumping and distribution systems will absorb some pressure increases but are not designed for surge control.

(4) Pump control valves as part of a surge control system including valve, power and manual valve, operators, accumulator, sensing and recording devices. This system automatically prevents water hammer in starting and stopping of pumps and should include safety features in its design to prevent damage from malfunctioning equipment. Design and operation of the surge control system should be coordinated with the manufacturer.

CHECKLIST OF INFORMATION REQUIRED FOR DETAILED SURGE AND WATER HAMMER ANALYSIS.

1. BASIC SYSTEM DIAGRAM OR SCHEMATIC
   a. Diameters, lengths, wall thickness of piping elements
   b. Elevations (pipeline, pump suction/discharge, etc.)
   c. Valve and fitting locations
   d. Pump location and arrangements
2. FLUID PROPERTY DATA
   a. Description of the fluid being transported (potable water)
   b. Specific gravity
   c. Bulk modulus of elasticity
   d. Fluid viscosity
   e. Temperature
   f. Vapor pressure

Figure 4-4. Checklist Surge and Water Hammer Analysis

3. PIPELINE DATA
   a. Type, class, maximum operating pressure, test pressure, allowance
   b. Pipe material and Young's modulus of elasticity
   c. Pipeline friction factor (Hazen Williams coefficient, Manning coefficient, Darcy Weisbach friction factor)
   d. Lengths (Actual lengths only). Equivalent lengths should not be used since minor losses will be lumped into a friction coefficient or a concentrated head loss item as appropriate
4. VALVE DATA
   a. Size and flow characteristics at various opening (C_v versus angle of opening)
   b. Valve operator speed and characteristics
   c. Type of check valves, damped or undamped
   d. Description of pump station discharge or suction control valves for normal operation and emergency operation
5. PUMP AND DRIVER DATA
   a. Pump perforance data (head, efficiency, horsepower, or torque versus flow)
   b. Number of stages (for specific speed calculation)
   c. Changes expected for increased throughput
   d. Rated conditions (conditions at the best efficiency point for head, flow, speed, and torque)
   e. Rotar polar moment of inertia WR^2 or equivalent WR^2, as viewed from the pump end for the driver, coupling, gearbox, pump and enclosed fluid as applicable
   f. Pump characteristics diagram or synoptic chart (if not available, curves from a pump of similar speed could be used
   g. Driver type (induction motor, synchronous motor, turbine, etc.)
   h. Driver torque versus speed curve (for pump start-up cases)
   i. Safe current versus time data for electric motors if start-up analysis is to be performed
   j. Special devices on pump/driver such as non-reverse ratchets, clutches, etc.
   k. Pump station controls description (minimum flow shutdown, flow discharge pressure shutdown, etc.)
6. OPERATIONAL DATA
   a. Normal start-up and shutdown procedures
   b. Emergency operational procedures
   c. Unplanned operations (inadvertent closures, pump shutdowns, etc.)
   d. Constraints on pipeline and equipment operation
7. KNOWN BOUNDARY CONDITIONS
   a. Constant head sources (reservoirs, tanks, etc.) and elevation of liquid surfaces
   b. Constant flow outlets or inlets
   c. Other known boundary conditions
8. SURGE SUPPRESSION DEVICES
   a. For water pipelines—Combination air and vacuum valves plus air release valve option, or air release option only (valve size, type, model number, location, etc.)
   b. Surge tanks (tank area and height)
   c. Accumulators (tank volume, initial gas volume, other parameters)
   d. Relief devices (set pressure, relief devices performance data)
   e. Specific surge control devices or schemes preferred

      Note: Parameters for surge suppression devices will usually be determined by the hydraulic transient studies.
9. REPORT REQUIREMENTS
   a. Type of report required (letter report or detailed engineering report)—number of copies
   b. Specific requirements

Figure 4-4. Checklist Surge and Water Hammer Analysis—continued

1) Type of pipe: New steel

2) Speed of shock wave: (a) 2,690 ft/sec

3) Fluid under control: water static head: (H) 20 ft

4) Length of main to nearest reservoir: 3,400 ft

5) Critical interval:

$$(t)\ t = \frac{2L}{a} = \frac{2 \times 3400}{2690} = 2.53 \text{ seconds}$$

6) Flow (gallons/minute) 5000 discharge line size: 10 in.

7) Normal system velocity: (V) 6.48 ft/sec

8) Surge head rise for instantaneous closure: (N = 1)

$$\Delta H = \frac{-a\Delta V *}{g\ N} = \frac{17431}{(32)\ (1)} = 544.7\ 236.1\ \psi$$

9) Total head of surge wave: (surge head plus static head)

$\Delta H + H =$ 20 + 545 = 565 ft = 245 psi

10) Number of critical intervals (t)

11) Seconds required for control cycle: (N x t) 1.6 x 2.5 = 4.1 seconds

12) Recommended control valve size: ** inches

13) Control valve head loss: ** ft

Derived from equations:

$$H - H_0 = F(t - \tfrac{x}{a}) + f(t + \tfrac{x}{a})$$

$$V - V_0 = \tfrac{-g}{a}\{F(t - \tfrac{x}{a}) - f(t + \tfrac{x}{a})\}$$

Solved simultaneously for instantaneous closure condition: f (t + x)=0

**Consult Manufacturer of Selected Equipment

Figure 4-5. Example Water Hammer Potential Calculation

SYMBOLS	DEFINITIONS
a	Speed of shock wave (ft/sec)
H	Static head (ft)
L	Length of watermain (pipe) (ft)
V	Normal velocity in pipe (ft/sec)
ΔH	Surge head rise (ft)
ΔV	Change in water velocity (ft/sec)
g	Acceleration due to gravity (ft/sec^2)
$\Delta H + H$	Total head of surge wave (surge head + static head)
N	Number of critical intervals (N + 1 for instantaneous closure)

NOTE:

H is for head

t is for time

V is velocity of flow

x is distance

a is acoustic velocity

F and f are functions representing the direct wave reflected wave respectively

Figure 4-5. Example Water Hammer Potential Calculation—continued